ART. XV.—*Fundamental Principles of Molecular Physics ;*
by Professor W. A. NORTON.

IN a recent work by Joseph Bayma, S. J. Professor of Philosophy, Stonyhurst College, England, in which a new theory of Molecular Mechanics is ably set forth, I find a brief critique of my theory of Molecular Physics, published, originally, in this Journal, and republished in the London and Edinburgh Philosophical Magazine. To this I propose to reply, and at the same time to remark incidentally upon some of the fundamental principles of the theory advanced by Professor Bayma. This can be most briefly and effectively done by taking up the

different objections urged by him in due order, and commenting upon them in succession ;—having a care not to dissociate remarks that should properly be presented together. The quotations made will be indicated to the eye by being printed in smaller type.

A great number of scientific men, to give an explanation of calorific, electric, and luminous phenomena, assume that æther pervades all ponderable bodies ; whence many of them have come to the conclusion, that every molecule of a body is surrounded by an æthereal atmosphere, the action of which is considered to be the source of those phenomena. Professor W. A. Norton, in a series of interesting articles published in the *American Journal*, gives a theory of molecular physics, of which the fundamental principle is, that each molecule is formed by an atom of ponderable matter surrounded by two æthereal atmospheres of a different kind. I give his words.

The established truths and generally received ideas which form the basis of the theory, are as follows :

1st. All the phenomena of material nature result from the action of force upon matter.

2nd. All the forces in operation in nature are traceable to two primary forces, viz : attraction and repulsion.

3rd. All bodies of matter consist of separate indivisible parts, called atoms, each of which is conceived to be spherical in form.

4th. Matter exists in three forms essentially different from each other. These are 1st, ordinary or gross matter, of which all bodies of matter directly detected by our senses either wholly or chiefly consist. 2nd. A subtile fluid, or ether, associated with ordinary matter, by the intervention of which all electrical phenomena originate, or are produced. This *electric ether*, as it may be termed, is attracted by ordinary matter, while its individual atoms repel each other. 3rd. A still more subtile form of ether, which pervades all space and the interstices between the atoms of bodies. This is the medium by which light is propagated, and is called the *luminiferous ether*, or the *universal ether*. The atoms, or “atomettes” of this ether, mutually repel each other ; and it is attracted by ordinary matter, and is consequently more dense in the interior of bodies than in free space.

5th. Heat, in all its recognized actions on matter, manifests itself as a force of repulsion.

The corner stone of a physical theory of molecular phenomena must consist in the conception that is formed of the essential constitution of a single molecule ; understanding by a molecule an atom of ordinary matter, endued with the properties and invested with the arrangements which enable it to exert forces of attraction and repulsion upon other molecules. In seeking for this, the most philosophical course that can be pursued is to follow out to their legitimate conclusions the general principles already laid down. . . . The conception here formed of a molecule involves the

idea of the operation of the two forces of attraction and repulsion: a force of attraction is exerted by the atom upon each of the two atmospheres surrounding it; and a force of mutual repulsion between the atoms of each atmosphere. These we regard as the *primary forces* of nature, from which all known forces are derived.

These are the capital points of Prof. Norton's ingenious theory. But we think that such a theory contains a great deal of arbitrary assumption. And indeed on what evidence are we to grant that matter exists in three forms essentially different from each other? Then how can we know the existence of atoms of gross matter having a spherical form, and therefore extended though indivisible? Why should we admit two æthereal fluids, which are both repulsive and only differ in subtlety? All this the learned Professor assumes without proof, apparently because it consists of "established truths and generally received ideas." But we say that no one has up to this day established the truth of such propositions. As for "received ideas," every one knows how often questionable notions have been and are received without serious examination, especially when expressed by Professors in a very dogmatic style. Are not a thousand hypotheses received? and do they cease to be hypotheses, although he who makes use of them for building a theory adorns them with the high name of principles.

This is all very plausible, but the objections urged are destitute of any real force. We will first consider the general intimation that the theory rests upon "a great deal of arbitrary assumption." No theory of Molecular Physics can, in the nature of things, have any other foundation than general principles to be regarded as hypotheses that have been rendered more or less probable, either by inductions from observation or by *a priori* reasonings. Molecular Physics cannot be erected, like Mathematics, upon a foundation known from the first to be eternally sure, that of self-evident truths. Mechanical axioms may exist as mere figments of the mind, and have often risen like bubbles in the minds of speculative philosophers, shone with an evanescent splendor, and suddenly burst at the touch of a hard fact. Our author is another instance of a learned philosopher who has faith in such unsubstantialities, and thinks to substitute them as a proper basis for a theory of Molecular Mechanics, in place of the general conceptions to which the progress of science leads, and by which alone its highest inductions find any explanation—regards the latter as arbitrary assumptions, and his own mental convictions of what matter must be and how it must act, as the only reliable foundation upon which to build. It is true that he takes exception to Principles 3rd and 4th, from the inductive point of view. Upon this ground—the only legitimate one to be occupied—I

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am quite ready to meet him : but I wish to enter here, at the outset, a demurrer against the virtual claim of the superiority of his own *à priori* method of establishing his fundamental principles. Such a claim is implied in the intimation that "no one has up to this day established the truth of such propositions ;"—as will be best appreciated by those who have read Prof. Bayma's book. Having proved, as he conceives, his propositions, and clinched each one of them with a Q. E. D., he insists that obvious intimations of Nature are to be discarded because the stamp of infallibility cannot be put upon them at once, before the test of availability in the explanation of phenomena has been applied. It was evident from the tenor of my exposition of the subject that the "established truths" referred to were merely regarded as having been virtually established, or rendered highly probable, by the inductions of science. The claim implied in Prof. Bayma's criticism, that they require a higher confirmation, in fact a demonstration of their truth, is not to be admitted.

He asks :

On what evidence are we to grant that matter exists in three forms essentially different from each other ?

A sufficient answer to the critic himself, is that pursuing a systematic course of deduction from his leading principles, and his assumptions of the essential nature of matter, he actually proves to his own satisfaction that matter does in fact exist in essentially three different forms. He reaches the conclusion that every primitive molecule consists of an attractive nucleus surrounded by a repulsive envelop. My own position is that every primitive molecule consists of an attractive atom of gross matter surrounded by a repulsive atmosphere of electric ether. The atom of gross matter answers to his attractive nucleus, the electric ether to his repulsive envelop. The difference of doctrine, from the present point of view, is in name only. In another connection he elaborately undertakes to prove that ether (i. e. the ether of space) is a "special substance." Thus he makes out that there are three essentially different forms of matter.

But to reply to others who may be disposed to adopt the objection urged. No one will deny the existence of gross or ponderable matter ; or of something which has all the mechanical attributes of matter. That an ether exists in space and within transparent media, we may certainly regard as abundantly established by optical phenomena. As to the electric ether, the evidence of its existence is that the great body of electric and magnetic phenomena, it is generally

conceded, admit of satisfactory explanation on the hypothesis of an electric fluid, or ether, intimately associated with matter; and that no successful attempt has yet been made to account for the simplest of these phenomena on any other hypothesis. Some physicists, it is true, are striving to do away with the supposed electric fluid;—prompted by the conjecture that Nature must operate by some simpler method, and work out all her wonderful diversity of phenomena by one, or at most, two forms of matter. Shall we wait until these physicists have realized their aspirations, at their discouraging rate of progress; or, guided by the indications of Nature, strive to link all natural phenomena together by a few recognized principles. A theory that shall accomplish this is the great desideratum. Even should such a theory not rest upon the highest and fewest possible mechanical principles, still the generalizations embodied in it must have their counterparts in certain physical truths, to the knowledge of which it will be likely to lead. It is by following the ascending grade of generalizations that speculative science has hitherto progressed. Preconceived notions of what matter must be in its essential nature, or by what form of matter, or varieties of method, Nature must operate have thus far contributed little to its advancement: and in fact when we consider that we positively know and can know nothing, *à priori*, with regard to the essential nature and condition of matter, and its means and mode of operation, such notions are entitled to little credit.

Our author implies in the remarks above quoted that the existence of an electric ether is not only not an “established truth,” but is to be ranked among those questionable notions that have been received without serious examination. This implication is obviously unjust. Besides, the serious examination that he has given the subject only leads him to confirm the substantial truth of what he would here seem to discredit—for, as we have already seen, his “repulsive envelope” is essentially my “electric atmosphere.”

Why should we admit two æthereal fluids which are both repulsive and only differ in subtlety.

Prof. Bayma and myself agree in admitting the existence of two *kinds* of matter,—attractive and repulsive; and as we have seen, three *forms* of matter. Is it inherently any less probable that two of these should be repulsive and one attractive, than as he assumes that two should be attractive and one repulsive:—viz., gross matter and the ether of space attractive, and the elements of the “repulsive envelope” repulsive. In the supposition that the two æthereal fluids differ in subtlety,

nothing more is essentially implied than that a considerable number of atoms of the one occupy the interstices between the atoms of the other. Prof. Bayma assumes equally great differences to subsist between his two attractive forms of matter. He remarks, "the distinction of such a medium" (a medium for the transmission of light) "from any ponderable substance, is not an hypothesis but a necessary inference drawn from observed facts;" and again, "I do not see how such a fact" (that light can pass undisturbed through air notwithstanding the immense number of air particles it encounters) "can be accounted for if æther is not immensely denser than atmospheric air." The reason for the conclusion is groundless, but it is the conclusion itself that we have here to notice. He adds "with this great density æther possesses also a very great subtlety."

I might also reply to Prof. Bayma, by asking him why we should admit, in order to explain electric and optical phenomena, two substances so distinct as the repulsive envelop of molecules, and the attractive luminiferous ether. The evidence of their similarity is much greater than of their dissimilarity.

In speaking of the two ethers as subtle, it was meant that a large number of their atoms occupied the interstices between the atoms of gross matter. It was also of course recognized that the velocity of propagation of a wave is much greater through either of the ethereal fluids than through a mass of ordinary matter. The only apparent force in the question under consideration, is derived from the fact that a vague conjecture is apt to be raised by it that a single ether may be equal to all the duty now assigned to both.

To proceed with our quotations:

What we have said on the constitution of molecules demonstrates indeed the necessity of granting to each molecule of ponderable matter a repulsive atmosphere, which we have called the *molecular envelope*. But this envelope is not of æther, since æther is not repulsive.

That is, is not of the same substance as his luminiferous ether, which he regards as attractive. But the "atmosphere" which corresponds in its direct operation with Prof. Bayma's "molecular envelope" is composed of electric matter, and this is repulsive. It is true that I conceive the interstitial spaces of this electric matter, and the space between it and the central atom to be pervaded by the ether of space; but the mechanical part chiefly played by this condensed universal ether consists in its being the medium in which pulses are originated that constitute the force of *heat repulsion*.

Had Professor Norton known the impossibility of continuous matter, he would have found out that what he calls an atom of gross matter comprises already not only the central element of a molecule, but its nuclei and its envelope; and consequently is already endowed with the properties and invested with the arrangements which enable it to exert forces of attraction and repulsion upon other molecules; without requiring any new and special atmosphere of electric or luminiferous æther.

That is, in other words, as already shown, Prof. Bayma's nucleus and envelop are in all outward relations precisely correspondent to my central atom and electric atmosphere. The only essential point of difference between us lies in the fact that I conceive that the interstitial luminiferous ether is condensed around the central atom, and is concerned in the production of some of the phenomena. It is not easy to see how Professor Bayma escapes the conclusion that his interstitial ether, which is attracted by the central nucleus, is condensed around it: still it is plain that he imagines that all natural phenomena are produced by the mutual actions of molecules composed of a central nucleus and a single repulsive envelop, without the intervention of any ether; except the luminiferous, in the case of the phenomena of light and radiant heat. This will appear from the following quotation:

As for the examples, by which he illustrates the theory, they consist of a series of phenomena of different kinds, the explanation of which does not show that the theory is not at fault. For it must be remarked, that those explanations do not imply the existence of extended atoms or of two distinct ætherial substances; and therefore the theory assumes more than is necessary for, or guaranteed by, the explanation of phenomena.

When he has shown this to be true of even the ordinary calorific and electric phenomena, we will admit that his objection to a second ethereal atmosphere interpenetrating the first, may have some force. He has given no hint of the general manner in which he supposes electric phenomena to be evolved. Heat he conceives to originate in the vibrations of the molecules of bodies; but, it can be proved almost to a demonstration, that heat cannot originate in this manner.

Our author proceeds as follows:

The atoms of gross matter being "indivisible" cannot be extended, and cannot be conceived to be "spherical in form, for if they were extended and indivisible they would be so many pieces of continuous matter, which we have already proved to be impossible.

To this I have the following replies to offer.

1. Professor Bayma assumes that every point of matter acts instantaneously upon every other point, at all distances however great or small, with a force having the same character at all distances, and inversely proportional to the square of the distance. This may seem probable, but is not self-evident; and in fact no reason can be assigned why one material point, having no extent, should act upon another with a force decreasing with the distance, according to any law whatever. The law of inverse squares is a consequence of wave propagation, or of radiations along definite lines, received on a molecule of definite size, and cannot be predicated of a force that acts instantaneously between two mathematical points. To suppose such a law is an arbitrary assumption.

2. If matter consists of material points, as supposed by Prof. Bayma, it is no more difficult to conceive of an atom of continuous matter, than of the space coextensive with it.

3. It is not more difficult to conceive of an indivisible atom acting as a whole upon another atom, with a certain energy, than of a mere point acting upon another point, and causing it to change its place; at the same time transferring to a new point all the properties it possesses.

4. If the occult nature of the force of action of one material point on another, be such that the intensity becomes indefinitely small at indefinitely small distances, instead of infinitely great as imagined by Prof. Bayma, then a collection of an infinite number of material points may form one invariable atom. Since the size of the atom may, in every instance, be so inappreciable in comparison with the distance between the nearest atoms, that there may never be any inequality of extraneous action on different points of the same atom, imparting different velocities to them, and so tending to break up the continuity of the matter. Besides, we have already seen that no inequality of elementary action, by reason of a difference of distance is legitimately deducible from Prof. Bayma's premises.

5. In speaking of atoms of gross matter as "indivisible," no other ground was intended to be taken than that each atom was indestructible from any possible action of another atom, and essentially invariable in form. This does not preclude the idea that the atom may be an aggregation of a finite number of material points; for it may be that the mutual action of two attractive points passes into a repulsion at excessively minute distances, and so that an atom of ordinary matter may be a system of material points, in either a statical or dynamical equilibrium. Indivisibility, taken in the only

sense in which the term can properly be used, does not then necessarily imply continuity, as maintained by Prof. Bayma.

6. The assumption that each atom is "spherical in form," was adopted merely as the simplest embodiment of the fundamental principles that the action of the atom was equal in all directions, and that the attractive action upon an atom of ether was neutralized at minute distances by the resistance developed at the point of contact. The existence of such a resistance necessarily implies that the elementary parts of the attractive atom, whether finite or infinite in number, act repulsively at very minute distances. But another conception may be formed of the mode of operation of an atom of gross matter, which involves no other supposition than that it acts equally outward in all directions from a center, and takes no account of its geometrical extent. This is, that *the effective attraction of the atom for the ether of space is due to the existence of a repulsion less than would be exerted by the one or more atoms of ether that would naturally occupy its place*. The result would be the condensation of an atmosphere of ether around the atom, without the exertion of any direct attractive force, or of any additional force of resistance. We may conceive the molecular atmosphere of electric ether to originate in a similar way; but as the opportunity of examining and testing this idea sufficiently has not yet been obtained, I shall continue to regard the electric ether as directly attracted by the atom of gross matter, and that the antagonistic force of resistance is furnished by the repulsion of the luminiferous ether condensed around the atom.

If, in accordance with these views, we seek for a possible origin of *gravitation*, we can find it in a primary attraction subsisting between atoms of gross matter. This must be excessively feeble in comparison with "molecular forces," and modify the effect of those forces only by creating a slight additional pressure of contiguous molecular atmospheres. Should we assume the primary actions between atoms of all kinds, to be wholly repulsive, and the effective attraction of the gross atom for both its ethereal atmospheres to be a mere consequence of inequalities of repulsion, it is conceivable that the attraction of gravitation might result from ethereal waves. as maintained by Professor Challis;—these waves having their origin in a *dynamical* equilibrium of the atmosphere of universal ether condensed around each atom.

Another critical remark is the following.

Again, æthereal substance according to the author, is repulsive; now this is inconsistent with astronomical facts, as we have sufficiently shown.

The principal astronomical fact, here referred to, is that the planets do not encounter any sensible resistance in their motion through space. The evidence of an ethereal resistance afforded by Encke's comet, Prof. Bayma strives to explain away without success. The fact that no sensible resistance is experienced by the planets does not necessarily imply, as he supposes, that the ether is not repulsive. For, in the first place, if the molecules of the planetary mass have the constitution I have attributed to them, the impinging ether must take effect upon either the ethereal or the electric atmospheres of the molecules, and so may be mostly expended in the generation of heat and electric currents. I have in fact undertaken to show, in my paper on *Molecular Physics*, that the earth may derive its magnetic condition, and a certain portion of its heat, from the impact of the ether of space. Again, if the action of gravity be not instantaneous it will take effect in a direction slightly inclined to the radius-vector, and, in the existing state of the planetary system, the tangential component resulting from this inclination may be in equilibrium with the feeble overplus of resistance from the ether. Besides, the supposed difficulty is not removed by substituting an attractive for a repulsive ether. It is true that when a molecule of the earth's mass encounters an atom of the ether on the line of its advance, it will, upon Prof. Bayma's ideas, pass through it, and leave it behind; but he has failed to note the fact that during the approach of the two, their relative velocity will be equal to the sum of the velocity of the earth and that due to their mutual attraction, and during their separation will be equal to the difference of the same velocities, and hence that the atom of ether will continue to attract the molecule during a longer interval of time while the two are separating than while they are approaching. The molecule will therefore on the whole, be retarded by the action of the atom. If the attractive ether be "immensely denser than atmospheric air," the resistance should certainly not be less than that of a subtile repulsive ether. If Prof. Bayma should still hold to the same line of argument, I do not see but he must abolish the ether of space altogether.

He continues :

Moreover, the writer, after having assumed that the electric and luminiferous ethers are both made up of atoms that repel each other assumes also that electric æther attracts luminiferous æther; for he admits that a molecule is formed of an atom of gross matter with two atmospheres, of which the first consisting of condensed luminiferous æther is attracted by the other, which consists of electric æther. Now if the atoms of electric æther are repulsive, how can they attract? So then we must conclude that Prof. Nor-

tons's theory as presented by him, in spite of the talent and learning of its author, cannot be adopted in science.

Prof. Bayma has here entirely misunderstood me, and represented what I threw out as a possible and perhaps probable conception, to be a fundamental principle of my theory. The real fundamental principle was that the atoms of electric ether repelled each other, and it was merely conjectured that this repulsion might be due to atmospheres of luminiferous ether condensed around the electric atoms, instead of being a direct repulsive action. It is a little singular that in view of this distinct statement of the manner in which the repulsion might result from a possible attraction, that our author should ask the question, "Now if the atoms of electric ether are repulsive, how can they attract?", and thereupon intimate the existence of a discrepancy fatal to the theory. It is in fact, altogether immaterial whether the mutual repulsion of electric atoms is indirect as conjectured, or direct.

It has now been made sufficiently apparent that the objections urged against my theory of molecular physics have no real force, and that its fundamental principles have not been disturbed. Whether it will ultimately be "adopted in science" or not, must depend upon its availability in rendering a satisfactory account of phenomena, and its ability to withstand the test of a detailed comparison with the entire range of physical facts. If life and health are granted me, I shall endeavor in good time to show, to the satisfaction of every candid mind, that the natural phenomena and experimental results, with their laws and features of diversity, that make up the different departments of Physics, are legitimately deducible from the fundamental principles of the theory; and that it presents claims to acceptance superior to those which can be urged in favor of any other theory.

The attempt to deduce the existing constitution of things and prominent phenomena, by Prof. Bayma from his fundamental ideas, so far as made, has certainly failed at several important points. To specify one or two of these. He obtains a curve of molecular action, that represents a repulsion at the smallest distances succeeded by an attraction at greater distances. This can only be made to represent the three states of bodies by conceiving the molecules of a gas to be in such a condition that if it were entirely freed from pressure, it would expand into a liquid. We know that many gases can be compressed into a liquid, but it is altogether gratuitous to suppose that they could be brought into a similar condition by a diminution of pressure. Experiment has given no indication of such a result or tendency.

Heat and light he conceives to originate in vibrations of gross molecules, but against this notion, as I shall take another occasion to show, insuperable objections may be urged. If this be given up, his explanation of the changes of the state of bodies must also be abandoned.

The doctrine that "transparent bodies transmit rays of light by the motions of their own molecules" will hardly be accepted, we think, by physicists. It would be a waste of time to argue against it.

Again the notion that a certain substance radiates light of a certain color because its molecules are made to vibrate in unison with the ray of that color, will not stand; for the results of spectral analysis show that the parts of a body which are capable by vibration of giving out any color, are precisely those which absorb and stifle that color. This fact, we may add, also proves conclusively that the rays cannot be transmitted by the motion of the molecules. Though so radically at variance with Prof. Bayma's theoretical views, it is in entire accordance with my own, for according to these, light originates in certain vibratory movements of the atoms of the electric atmospheres of molecules, and when these vibrate naturally in unison with the ray of any color that falls upon them, they take up its vis viva, and so the ray is transformed into a molecular electric current.

As to the "leading principles" laid down by the author, they may in the main be conceded; but these by no means cover the whole ground upon which his theory is raised. We find, for example, that he assumes that all elements or material points of the same form of matter act, under similar circumstances, with the same intensity. Now if this principle be admitted, what theoretical basis have we for the existence of distinct primitive molecules for every different substance;—the number of elements associated together being exactly the same for each primitive molecule of each substance, and different for primitive molecules of different substances. The natural tendency would be to a fortuitous association of elements in an endless variety of numbers, into groups. No controlling principle by which uniformity would be evolved from chaotic confusion, is furnished by the theory. The Hand of the Creator must be supposed to have miraculously interfered, and guided each element to its precise place, in the formation of every molecule of matter. The objection here urged, derives still greater force from the consideration that both the nucleus and envelop of each specific molecule are assumed to have a regular geometrical form, different for each substance. To assume the existence of such molecules, is to make an incalculable number of arbitrary

assumptions. No such exception can be taken to the views I have advocated. For primarily each specific atom of gross attractive matter must appropriate to itself from the universally diffused repulsive ethers, its electric and its ethereal atmosphere, each of a certain definite extent. Upon the relations of these specific atmospheres to the central atom and to one another, all the different properties of each specific molecule must depend.

We have already seen that the principle that one material point acts upon another, instantaneously, without the intervention of any medium, is opposed to the fundamental idea that the force exerted is inversely proportional to the square of the distance. This law, to say the least, is an arbitrary assumption in the premises. The author also conceives that the mutual action of two material points, is in no degree and under no circumstances intercepted by another intervening point. But we know that in the case of the molecular forces, the amount of vis viva expended in imparting motion to one particle is abstracted from the force in action, and according to Prof. Bayma, the molecular forces are of the same nature as the forces subsisting between the material elements. The force of gravity, it is true, is not sensibly intercepted, but this does not prove that a tendency to interception does not exist; for, upon the supposition of a wave transmission of the force, the effective attraction of any molecule may be the mere differential of the actual force transmitted, and besides, in the circular revolution of a planet the distance from the sun remains unchanged.

My own doctrine is, that the molecular forces, including the heat-repulsion, are dynamical forces, transmitted by wave-propagation and developed by the primary forces of attraction and repulsion, subsisting between the atoms of gross matter and those of the electric matter and the ether of space. The primary forces determine the electric and ethereal atmospheres of molecules, originate the molecular forces proper, and also when an inequality of electric condition is produced on two contiguous molecules or bodies, by molecular actions, gives rise to the special forces of electric attraction and repulsion. The waves of heat and light originate in the ethereal atmospheres of molecules, and are developed by vibrations of the atoms of the electric atmospheres, toward and from the center of each molecule and the region of ethereal disturbance. By reason of the varying conditions of equilibrium the rate of vibration increases, and its intensity or vis viva, decreases, in proportion as the electric atom is more remote from the center of the molecule. Thus, of the different colored rays, the red proceeds from the lowest depth in the electro-ethereal atmosphere. The obscure heat rays originate at a still lower depth. Heat and light may also

originate in the space between two molecules in the act of combination, or near approach, by reason of the condensation of the interstitial electric ether toward the line of the centers, resulting from the oblique attractive action of the molecules. In this condensation of the electric ether between molecules that are urged nearer to each other, and the expansion of the same when they are separated, we find the key to the explanation of the different modes of electric excitation (that of the galvanic current included). The secret of the intimate relations between electricity and heat and light, is obvious in view of what has been stated.

The ethereal atmospheres of molecules, besides playing the part already signalized, are the chief determining cause of the diverse phenomena that attend the transmission of light through transparent media. Thus *refraction* is chiefly due to the retardation attending the propagation of the ray around from one side to the other of the molecular atmospheres; *dispersion* of the rays in the spectrum, to the fact that the rays of the greatest intensity, and slowest rate of vibration, penetrate to the greatest depth in the molecular atmospheres, pass around in smaller circles, and thus suffer the least retardation; and *double refraction* to the fact that the atmospheres have a spheroidal form, owing to unequal molecular compression on different sides.